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(58) Field of search

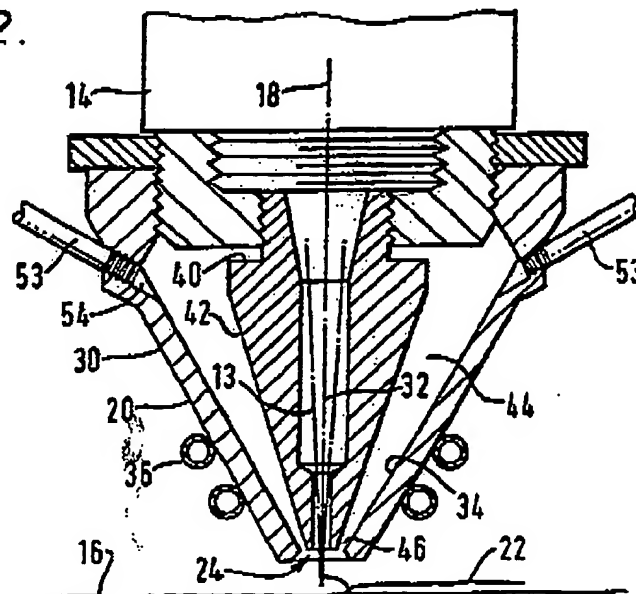
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(54) Laser welding apparatus and process

(57) Laser welding apparatus includes a laser whose beam is focused to a focal point above, below, or at the surface of the welding substrate with a power density sufficiently high to melt a portion of the substrate to form a weld puddle. A laser welding nozzle delivers powder to the weld puddle uniformly around its circumference from a powder feed system, and an axial gas flow system flows gas through the nozzle toward the substrate to modify the powder flow and protect the apparatus from damage by the intense heat. The laser welding nozzle preferably includes outer 30 and inner 40 frustoconical housings that define an annulus 44 therebetween, and powder mixed with a fluidizing gas is metered through the annulus and to the weld puddle 62, where it later solidifies to form a weld bead.

FIG. 2.



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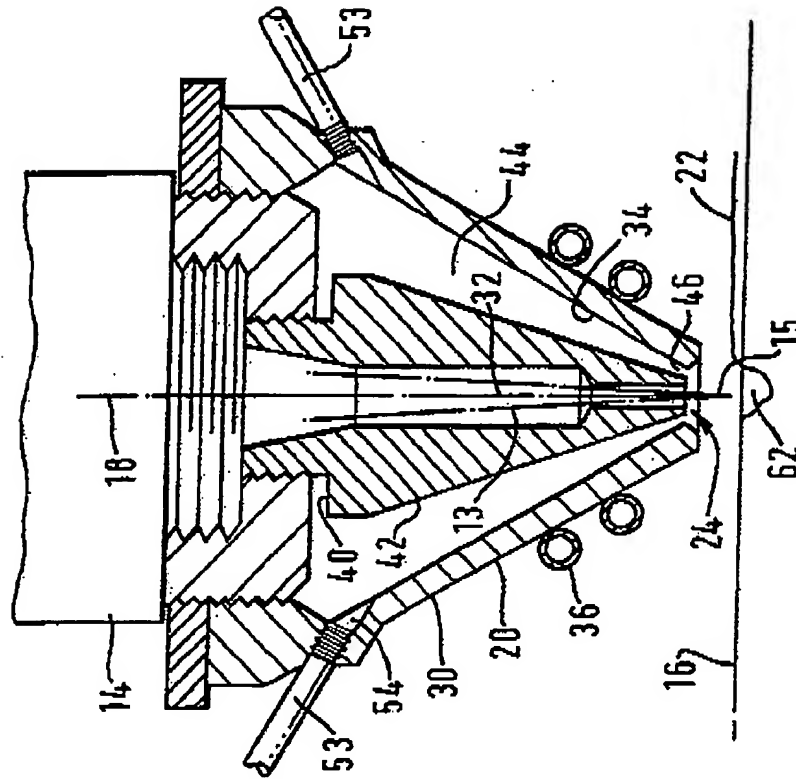


FIG. 2.

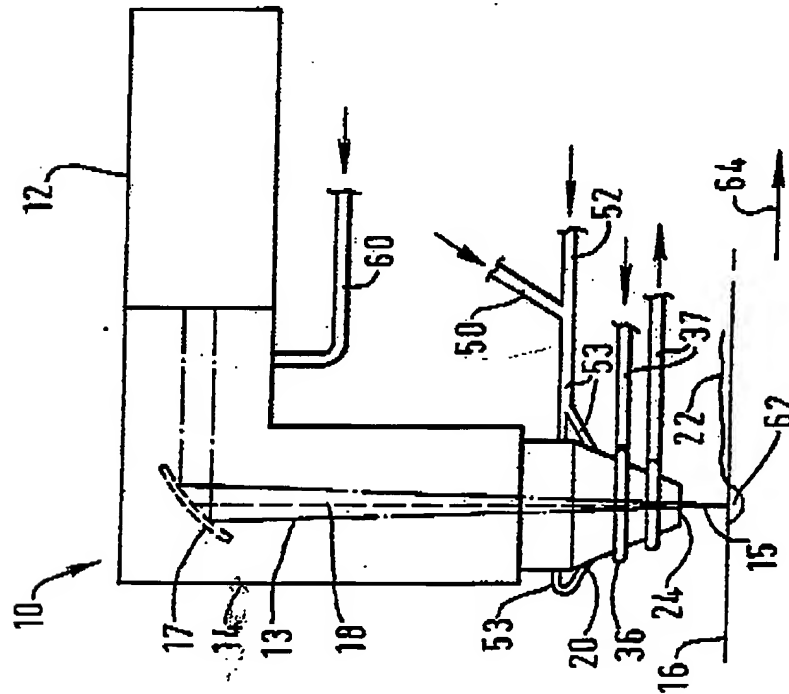


FIG. 1.

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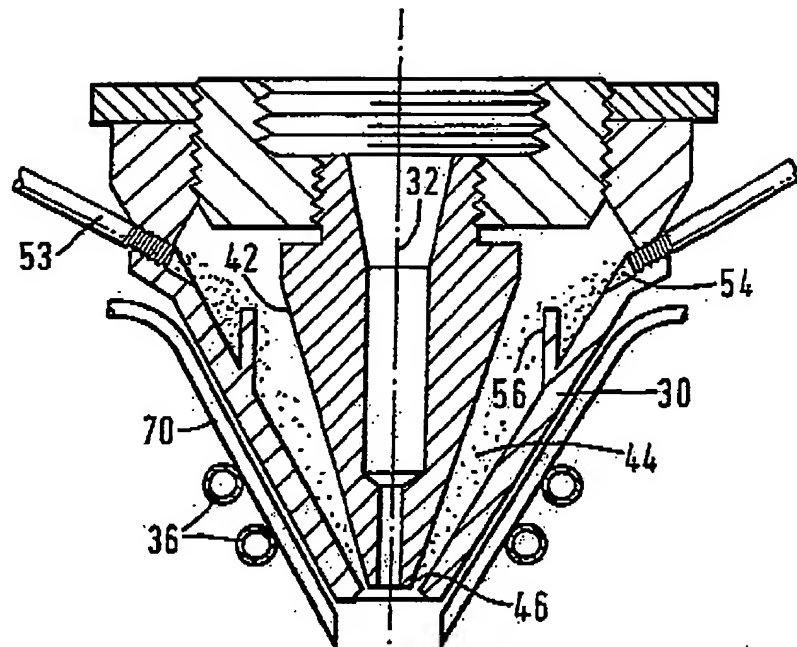


FIG. 3.

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LASER WELDING APPARATUS AND PROCESS

This invention relates to a laser welding apparatus and to welding processes. The present invention primarily concerns surface welding, although it may be  
5 utilized in relation to other welding applications.

Welding is a process in which two or more pieces of material are joined together. In a familiar type of welding, a welding torch is used to melt the facing surfaces of two parts, and the facing surfaces are fused together. A filler  
10 or feed material may be added to the welded area to impart particular properties or form a part of the bonded region. In its most general sense, welding can also be accomplished by solid state methods such as diffusion bonding, but in the narrower sense used herein both materials to be joined must be  
15 at least partially melted.

In another type of welding, a surface layer is added to a substrate by melting a region at the surface of the substrate, adding a feed material to the molten pool with the result that there is an intermixing and fusing of the feed  
20 material and the substrate, and thereafter permitting the molten material to solidify. This technique is widely used for many purposes, often to add hard surface facings such as wear-resistant coatings to softer substrate materials, and to

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build up or repair parts that have failed, worn out, or were made undersize initially.

Many different types of sources have been used to supply the energy used to melt the substrate and feed material in welding processes. Electric arcs and torches are routinely utilized. The heat generated by friction is used in friction welding.

More recently, the intense heat generated by a laser has been used in welding operations to melt the substrates and feed materials. U.S. Patents 4,200,669, 4,730,093, and 4,743,733, whose disclosures are incorporated by reference, disclose laser welding operations. In each case, the output beam of an industrial laser is focused to a point near to or within the substrate, so that the intervening surface regions of the substrate are heated and melted by the focused laser beam. A feed material may be introduced into the laser beam or the molten pool, if desired. The great versatility available through the use of laser heating has resulted in widespread use of lasers in welding and other metalworking operations.

Laser welding has been demonstrated to be operable, but in practical applications has sometimes been inconvenient. The apparatus illustrated in U.S. Patent 4,200,669 injects a stream of powder feed material into the beam, and precise

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control of the powder in relation to the beam is difficult. The approach illustrated in U.S. Patents 4,730,093 and 4,743,733 provide a major improvement in controllability, but utilizes a directional component to the powder feed. That is, 5 if the relative movement of the laser beam and substrate is as illustrated in Figure 5 of the '093 patent, powder is fed from the rear of the weldment. If relative movement instead is out of the plane of the paper, the powder is fed from the side of the weldment, unless a special carriage is provided to pivot 10 the powder conduit. The result is a weldment whose characteristics vary depending upon relative directions of movement of the substrate and the heat source.

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In accordance with the invention, laser welding apparatus for depositing a feed material onto a substrate comprises a laser; means for focusing the beam of the laser to a focal point sufficiently near to the surface of the substrate to melt a region of the substrate, thereby forming a weld pool; and means for supplying a feed material to the weld pool uniformly around its circumference. Preferably, the means for supplying includes a nozzle having an outer housing and an inner housing that define a converging annular passage-  
5 way therebetween, the feed material being supplied to the nozzle at the diverging end of the passageway and being conveyed toward the converging end of the passageway. In this manner, the feed material is supplied uniformly around the circumference of the weld pool, and there is no directionality  
10 observed in the weldment when the direction of relative movement of the apparatus and the substrate is changed.

More specifically in relation to a preferred approach, laser welding apparatus comprises a nozzle having a

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frustoconical outer housing, and a frustoconical inner housing of smaller conical size than the outer housing and fitting therein with the frustoconical axes of the outer and inner housings coincident, the outer housing and the inner housing defining a converging annular passageway therebetween; a laser; an optical system configured to direct the beam of the laser along the frustoconical axis of the outer and inner housings to a focal point outside the nozzle; a gas supply system communicating with the interior of the inner housing, creating a flow of gas from the inner housing toward the focal point of the laser; and a feed system communicating with the annular passageway between the inner housing and the outer housing and adapted for introducing thereto a flow of finely divided feed material mixed with a carrier gas.

The present invention also extends to a process for laser welding with a supplied feed material. In accordance with this processing aspect of the invention, a process for depositing a layer of a feed material onto a substrate comprises the steps of furnishing a laser and optical system that focuses the beam of the laser to a focal point sufficiently near the surface of the substrate that a region of the substrate is melted to form a weld pool; and adding a finely divided feed material to the weld pool, the feed material being added uniformly around the circumference of the weld pool.



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An embodiment of the present invention provides a laser and optical system that focuses the laser beam to a focal point sufficiently close to the surface of the substrate that the surface regions are melted to form a weld pool. The actual focal point of the laser may be below, coincident with, or above the surface of the substrate, but in any event the power density in the region of the focal point is sufficient to melt the substrate material. A circumferential housing attached to the end of the optical system enclosure encircles the laser beam. The housing includes an inner housing and an outer housing with a downwardly and inwardly sloping annular passageway defined therebetween. Powder fluidized in a gas flow is fed to the upper end of the annulus through discrete ports, and is distributed around the annulus as it falls. An interior wall within the annulus may be provided to improve the circumferential powder distribution. Where such a wall or dam is provided, the powder introduced through the ports enters the contained volume behind the dam, and later spills over the dam in a circumferentially uniform pattern. The converging opening at the lower end of the annular passageway directs the powder toward the melted weld pool. The powder may enter the laser beam before it reaches the weld pool, so that the powder may be partially or completely melted when it enters the weld pool.

A flow of axial gas flows through the inner housing and toward the substrate. The flow of axial gas prevents

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damage to the optical system and laser by acting as a barrier to the weld splatter and smoke. The flow of axial gas also may contribute to the formation of a plasma near the focal point of the laser, if the laser beam energy density is

5 sufficiently high to create such a plasma by ionizing gas atoms and vaporized atoms of the feed material and substrate material. The axial gas flow also directs the feed material toward the substrate and weld pool, where the metal is deposited. The heated or molten droplets of feed material mix with

10 the molten material of the weld pool, and the mixture in the weldment solidifies as a bead that typically protrudes above the original surface of the substrate because of the added mass of feed material.

The nozzle assembly of the present invention permits

15 the introduction of a controlled flow of powder into the weld puddle. The mass flow of powder is varied by controlling the flow rates of powder and fluidizing gas in the powder feed system. Powder is introduced into the weld pool uniformly around its circumference by the annular passageway. Normally,

20 the laser beam is perpendicular to the substrate. With the nozzle, a change in the direction of relative movement of the beam over the surface of the substrate does not require any adjustment of the powder feed mechanism nor alteration of the speed of the relative movement to permit

25 adjustment of the feed mechanism. The present apparatus is also highly compact and contained within an easily grasped and

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A better understanding of the present invention will be apparent from the following more detailed, and illustrative, description of the preferred embodiment, taken in conjunction with the accompanying drawings, in  
5 which:

Figure 1 is an elevational view of an illustrative apparatus of the invention, with the laser beam path shown in cutaway view;

10 Figure 2 is a side sectional view of the welding nozzle of the apparatus; and

Figure 3 is a view similar to Figure 2 of another embodiment of the invention, including a powder flow control dam.

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A laser welding apparatus 10 is illustrated generally in Figure 1. The apparatus 10 includes a laser 12 having a beam 13 that, when focused by an optical system 14, is of sufficient power density to melt a  
20 portion of the adjacent substrate 16 and melt (or heat) a feed of finely divided feed material. The beam 13 of the

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laser 12, having a beam axis 18, is convergently focused by the optical system 14 to a focal point 15. (In the system illustrated in Figure 1, the convergent focusing is accomplished by a convergent mirror 17, but a lens may be used.)

5 After leaving the optical system 14, the beam 13 enters a welding nozzle 20, whose structure and operation are described in more detail below. The nozzle 20 introduces finely divided feed material into the melted portion of the substrate, where the finely divided feed material is melted. The feed material  
10 mixes with the molten substrate material and quickly solidifies in the form of a bead 22, as heat is removed to the underlying unmelted substrate. The operating distance from the tip of the nozzle 20 to the substrate 16 is typically about 0.2 inches. The flow of feed material is narrow,  
15 unidirectional, and collimated, and the nozzle 20 is close to the substrate 16.

Referring to Figure 2, the nozzle 20 includes an outer housing 30 which is threadably engaged to the end of the optical system 14 so that a central axis 32 of the housing 30  
20 coincides with the beam axis 18 of the laser. The housing 30 is hollow, so that the laser beam 13 may enter at the end attached to the optical system 14, pass through the housing along the central axis 32, and exit at the other end. The threaded engagement permits the outer housing 30 to be ad-  
25 justably moved toward and away from the optical system 14, with the central axis 32 of the housing 30 remaining

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coincident with the beam axis 18 of the laser 12. This adjustability permits the location of the focal point 15 of the laser to be adjustably moved axially relative to the housing 30, without changing the optical system. The external surface of the outer housing 30 is generally irregularly frustoconical in shape. Preferably, several turns 36 of tubing are fastened to the external surface of the outer housing 30, and cooling water is supplied to the turns of tubing through cooling water lines 37. The inner surface of the outer housing 30 includes a frustoconical surface 34 at the end thereof remote from the attachment point to the optical system 14.

Disposed within the outer housing 30 and threadably engaged thereto is an inner housing 40. The inner housing 40 is also hollow, with the same central axis 32 as the outer housing 30. The laser beam 13 thus also travels through the inner housing 40 along the central axis 32. The threaded engagement of the inner housing 40 to the outer housing 30 permits the axial position of the two housings to be adjusted relative to each other, thereby changing the size of the annular passageway, to be described below. The inner housing 40 includes a frustoconical surface 42 at the end thereof remote from the optical system 14 and adjacent the frustoconical surface 34 of the outer housing 30. The two frustoconical surfaces 34 and 42 are in a generally facing relationship to each other, defining a converging annular

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passageway 44 therebetween. Relative axial movement of the inner housing 30 and the outer housing 40 enlarges or reduces the area of the annular passageway 44.

Preferably, the conical half angle of the frustoconical surface 34 of the outer housing is 2-10 degrees more than the corresponding conical half angle of the frustoconical surface 42 of the inner housing, so that the annular passageway converges slightly adjacent an exit point 46 thereof. In a preferred embodiment, the conical half angle of the surface 34 is from about 20 to about 45 degrees, most preferably from about 30 to about 35 degrees, and the conical half angle of the surface 42 is from about 20 to about 35 degrees but about 2-10 degrees less than the conical half angle of the surface 34. The converging character of the annular passageway 44 causes the flow of the powder in the various parts of the annulus to be focused toward a common point of confluence located along the central axis 32 and thence coincident with the laser beam axis 18. One of the controllable parameters of the apparatus 10 is the relative location of the beam focal point 15 and the point where the flow of powder intersects the central axis 32. In some instances, for particular operating conditions, it is desirable that the laser beam focal point 15 coincide with the confluence point of the powder flow, but in other conditions they may not be coincident. In normal operation, the powder is directed toward the melted region of the substrate, and the

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laser beam is focused above, below, or at the substrate surface.

Finely divided feed material, preferably in the form of powder, is introduced into the apparatus 10 through the annular passageway 44 at its upper or divergent end. A powder feed system includes a source of the powder and fluidizing mechanism (not shown) that delivers powder through a powder supply tube 50 to several powder delivery tubes 53. The fluidized powder flows from the tubes 53 to the annular passageway 44 through a number, typically 2 or 4, of discrete injection ports 54, located symmetrically at the head of the annular passageway 44, upstream of the exit point 46. The introduced powder distributes around the circumference of the passageway 44, flows toward the exit point 46 under the force of gravity and the pressure of the carrier gas flow, and exits the passageway 44 toward the powder focal point.

It has been found that, for some types of powders and feed materials, the circumferential distribution of the powder around the annular passageway 44 is not as uniform as might be desired. To increase the uniformity of the circumferential distribution, a powder dam 56 is added as an inward projection from the inner wall of the frustoconical surface 34 of the outer housing 30, just below the point of introduction of the powder through the injection ports 54. Figure 3 illustrates this embodiment, wherein other elements are as previously described. In this embodiment, fluidized

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powder feed material is introduced through the injection ports 54 into the volume behind the dam 56. This volume fills, and powder spills over the dam 56, into the lower portion of the annular passageway 44, and thence to the exit point 46 in the manner previously described. The rate of overflow of the powder is equal to the total flow rate of powder through the powder supply tube 50, at steady state operation. The overflow is circumferentially uniform, leading to a circumferentially uniform flow of powder through the exit point 46.

10 An axial gas flow is provided to the nozzle 20 by an axial gas flow line 60 that communicates with the interior of the nozzle 20, either directly through the wall of the nozzle 20, or through the wall of the optical system 14, in the illustrated embodiment of Figure 1. Axial gas flows from the line 60 through the interior of the optical system 14 and nozzle 20, toward the substrate 16. The axial gas flow protects the optical system and nozzle from damage by a backflow of weld splatter, smoke, and heat, cools the nozzle, and also aids in directing the feed material towards the substrate.

20 In the preferred approach, the surface of the substrate 16 is protected during welding by a cover gas that envelops it and prevents oxidation. The cover gas typically an inert gas such as argon, is supplied by several sources.

25 The axial gas and fluidizing gas provide a portion of the cover gas, as they usually are partly or entirely inert gas.



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An external gas flow around the entire nozzle 20 may be provided by an external tube (not shown). A cover gas flow may be provided through the apparatus 10 itself. As illustrated in Figure 3, one or more cover gas tubes 70 may be  
5 attached to the outer surface of the outer housing 30, with the flow of the cover gas therein directed toward the weld pool 62 and its general neighborhood. The inert gas flows tend to prevent oxidation or other environmental damage to the metal in the weld pool and bead while it is hot.

10 The laser beam 13 is focused by the optical system 14 to the focal point 15 on the beam axis 18. The focal point 15 may be above, below, or coincident with the surface of the substrate 16. The positions of the nozzle 20 relative to the substrate 16 and of the beam focal point 13 relative to the  
15 nozzle 20 are adjusted so that the energy density of the laser beam near the focal point 15 is sufficient to melt a region of the substrate below the nozzle 20, forming a molten or weld pool 62. The feed material, which may be molten or partly molten before it reaches the weld pool 62, is directed into  
20 this pool 62 and mixes with the molten material of the pool. As the substrate 16 is moved relative to the apparatus 10 in the direction indicated by the arrow 64, the weld pool 62 is moved over the surface of the substrate 16, causing the bead 22 to lengthen and follow the trail of the apparatus 10.

25 The power density of the beam 13 is greatest at the focal point 15. If the power density is sufficiently great at

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this or any other location, the interaction between the axial gas, the carrier gas, the powder, and the energy of the laser beam results in the formation of a plasma. The plasma is a highly ionized cloud of ions and electrons that reaches an  
5 extremely high temperature within a limited volume. In this volume, a portion of the feed material is normally melted. The energy of the laser beam strips electrons from the plasma-forming gas atoms and the vaporized feed material atoms. The plasma, once initiated or "lit", becomes self sustaining if  
10 the flow of gas and feed material, and the laser beam, are maintained. The apparatus 10 may be operated either with or without formation of a plasma.

Preferably the finely divided feed material forms an inverted cone as it exits from the nozzle 20. That feed  
15 material cone has a focal point which may be adjusted, i.e., the feed material focal point may be moved toward or away from the nozzle 20. Such adjustment of the feed material focal point is accomplished by rotation of the inner housing 40 relative to the outer housing 30. Such rotation moves the  
20 inner housing 30 axially and either enlarges or decreases the size of the annular passageway 44, particularly at its lower end. When the passageway 44 is made smaller in size, the feed material cone and its focal point are also changed. The feed material focal point and the laser beam focal point may be ad-  
25 justed to coincide, to melt the feed material.

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At least a portion of the finely divided feed material is usually completely or partially melted by the laser beam, and other portions may intentionally or unintentionally remain unmelted. In some uses, such as the application of wear-resistant coatings, it may be desirable that a portion of the feed material remains unmelted. For example, the feed material may include finely divided ceramic powder, which, when deposited as particles on the surface of the substrate, increases wear resistance of the substrate.

10 The following structural and operational details of an embodiment of the present approach are provided by way of additional information and not of limitation. The maximum outer diameter of the outer housing is about 2.5 inches, and the diameter of an ejection opening 24 is about .125 inches.

15 The nozzle is operated with the housing 30 and 40 adjusted so that the width of the annular passageway 44, at the exit point 46, is about .060 inches. The gas flow rate of the axial gas is between 2 and 15 cubic feet per hour. In typical operating conditions, the flow rate of powder is about 7 grams per

20 minute. The powder focal point 48 is adjusted to be coincident with the substrate at the weld puddle 62. The length of the nozzle is about 4 inches, but the dimension is not critical. The laser is a carbon dioxide laser operated at a power level of 100-5000 watts, in a pulsed or CW mode.

25 Either the substrate or the nozzle, or both, is moved so that there is relative movement between the substrate

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and the nozzle. Preferably the nozzle is fixed and the substrate is automatically progressed under the substrate on an electro-mechanical table having X and Y axis of movement, the movement being under programmed computer control as to  
5 speed and direction of motion.

A number of different gases and gas mixtures have been utilized for the axial gas flow, including argon, nitrogen, helium, hydrogen, \_\_\_\_\_ and mixtures thereof. Argon has been used for the powder carrier gas. A  
10 variety of metallic and nonmetallic feed materials have been deposited, including ceramics. Such materials that may be deposited into the weldment include titanium alloys such as Ti-6Al-4V, tungsten, cobalt alloys, nickel alloys such as IN 718, and ceramics.

15 Although the present invention has been described in connection with specific examples and embodiments, it will be understood by those skilled in the arts involved that the present invention is capable of modification.

20 Embodiments of the present invention provide a versatile tool for depositing materials onto substrates.

Embodiments provide an improved laser welding apparatus and method, which enjoys the advantages of prior laser welding techniques and also has improved control of  
25 power introduction and quality of the finished structure.

Embodiments of the present invention provide a laser welding apparatus in which the heating of the substrate is controllable, and the introduction of feed

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metal is not directional. Weldment character is therefore unchanged when the direction of relative movement of the welding apparatus and the substrate are changed. There is no need to dwell at corners or change the rate of traverse  
5 of the weld head, avoiding another of the variables known to effect weldment quality. The apparatus is compact to fit within restricted spaced. The introduction of feed material is precisely controlled and varied as necessary, and the point of introduction of the powder relative to  
10 the weld pool and focal point of the laser beam is readily controlled.

An embodiment of the invention is also highly compact and contained within an easily grasped and manipulated structure, improving the ease of use of laser  
15 welding in a manufacturing environment.

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CLAIMS:

## 1. Laser welding apparatus, comprising:

a nozzle having

a frustoconical outer housing, and

a frustoconical inner housing of smaller conical size than the outer housing and fitting therein with the frustoconical axes of the outer and inner housings coincident, said inner housing being axially adjustable relative to said outer housing, the outer housing and the inner housing defining a converging annular passageway therebetween;

a laser;

an optical system configured to direct the beam of the laser along the frustoconical axis of the outer and inner housings to a focal point outside the nozzle;

a gas supply system communicating with the interior of the inner housing, creating a flow of gas from the inner housing toward the focal point of the laser; and

a feed system communicating with the annular passageway between the inner housing and the outer housing and adapted for introducing thereto a flow of finely divided feed material mixed with a carrier gas.

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2. The apparatus of claim 1, wherein the laser beam passes along the centerline of the inner housing.

3. The apparatus of claim 1 or 2, wherein the laser is a carbon dioxide laser.

4. The apparatus of claim 1, 2 or 3, wherein the optical system includes a mirror to focus the laser beam.

5. The apparatus of claim 1, 2, 3 or 4, further including a powder dam disposed within the annular passageway.

6. A process for depositing a layer of a feed material onto a substrate, comprising the steps of:

furnishing a laser and optical system that focuses the beam of the laser to a focal point sufficiently near the surface of the substrate that a region of the substrate is melted to form a weld pool; and

adding a finely divided feed material to the weld pool, the feed material being added uniformly around the circumference of the weld pool;

wherein the step of adding is accomplished by furnishing a laser welding nozzle having an outer housing and an inner housing that define a converging and adjustable annular passageway therebetween, the feed material being supplied to the nozzle at the diverging end of the passageway

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and being conveyed toward the converging end of the passage-way.

7. The process of claim 6, wherein the finely divided feed material is mixed with a fluidizing gas prior to being supplied to the nozzle.

8. The process of claim 6 or 7, wherein a flow of gas is directed through the interior of the inner housing toward the substrate.

9. The process of claim 8, wherein the gas is selected from the group of gases consisting of argon, nitrogen, helium, hydrogen, and mixtures thereof.

10. The process of claim 6, 7, 8 or 9, wherein the feed material is selected from the group consisting of a titanium alloy, a nickel alloy, a cobalt alloy, and an iron alloy.

11. The process of claim 6, 7, 8, 9 or 10 wherein the focal point of the laser is within the substrate.

12. The process of claim 6, 7, 8, 9 or 10, wherein the focal point of the laser is above the substrate.



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13. A laser spray ——— nozzle assembly, comprising:

(a) a nozzle body with first and second spaced apart end portions and a beam passageway extending therebetween for permitting a laser beam to enter said passageway through said first end portion and to exit through said second end portion;

(b) a housing surrounding said second end portion and spaced therefrom and forming an annular passage therewith and including an opening coaxial with said beam passageway for permitting a laser beam to pass therethrough;

(c) means operably associated with said passage for supplying a powder thereto so that the powder and the beam converge on a common location:

14. The assembly of claim 13, wherein:

(a) means are associated with said passage for uniformly distributing the powder about said passage.

15. The assembly of claim 12 or 14, wherein:

(a) said second end portions are frustoconical;  
and,

(b) said housing has a lower portion tapering toward said opening and conforming to said second end portion for therewith providing a gap of uniform dimension.

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16. The assembly of claim 15, wherein:

- (a) means being operably associated with said nozzle body for moving said body along the axis thereof for adjusting the spacing of said frustoconical portion relative to said tapered portion and thereby regulating the flow of powder through the outlet.

17. The assembly of claim 15 or 16 including:

- (a) means operably associated with said body for moving said body and thereby positioning said second portion relative to said lower portion.

18. The assembly of claim 13, 14, 15, 16 or 17, comprises:

- (a) means operably associated with said housing for cooling said housing.

19. The assembly of claim 13, 14, 15, 16, 17 or 18, comprises:

- (a) means operably associated with said first end portion of the nozzle body for cooling said first end portion.

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20. The assembly of any one of claims 13 to 19,  
wherein:

- (a) means are associated with said nozzle body  
for focusing the beam.

21. The assembly of any one of claims 13 to 20,  
further comprising:

- (a) laser beam generating means coupled with  
said body.

22. A nozzle for a laser cladding system, comprising:

- (a) laser beam generating means;
- (b) a generally cylindrical apertured housing  
having a first end portion operably  
associated with said generating means for  
receiving a laser beam and a second end  
portion positionable adjacent a workpiece  
so that the laser beam exiting said second  
end portion is directed at the workpiece;
- (c) a recess in said second end portion coaxial  
with said aperture forming a powder  
distribution chamber and said chamber  
having an outlet coaxial with said  
aperture;

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- (d) an apertured nozzle body coaxially positioned in said housing and including a beam receiving passageway through which the generated beam passes; and,
- (e) powder distribution means positioned within said chamber for distributing powder therein so that the beam and the powder exit said housing and converge on a common location.

23. The nozzle of claim 22, wherein:

- (a) said body has a frustoconical portion disposed adjacent said outlet;
- (b) said second end portion tapers toward said outlet for forming a gap with said frustoconical portion; and,
- (c) cooling means are operably associated with said second end portion.

24. The nozzle of claim 22 or 23, wherein:

- (a) means are associated with said body for moving said body along the axis thereof for regulating said gap and thereby controlling the flow of powder through said outlet.

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25. A laser cladding method, comprising the steps of:

- (a) providing a laser nozzle assembly having a central beam passageway and an annular coaxial powder dispersing chamber;
- (b) positioning a workpiece adjacent the nozzle assembly outlet;
- (c) simultaneously directing the beam and the powder at a common location on the workpiece so that the beam melts a thin layer of the workpiece and the powder becomes dispersed within the molten layer; and,
- (d) advancing the nozzle assembly relative to the workpiece.

26. A laser welding apparatus substantially as hereinbefore described with reference to Figure 1 optionally together with Figure 2 or Figure 3 of the accompanying drawings.

27. A process of welding substantially as hereinbefore described with reference to Figure 1 optionally together with Figure 2 or Figure 3 of the accompanying drawings.